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Executive Function in Obsessive-Compulsive Disorder: A Worldwide Mega-Analysis of Task-Based Functional Neuroimaging Data of the ENIGMA-OCD Consortium

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ABSTRACT

BACKGROUND: Obsessive-compulsive disorder (OCD) is associated with impaired executive function and altered activity in associated neural circuits, contributing to reduced goal-directed behavior. To investigate neural activation during executive function, we conducted a mega-analysis in the ENIGMA-OCD consortium pooling individual participant data from 475 individuals with OCD and 345 healthy control participants across 15 functional magnetic resonance imaging (fMRI) tasks collected worldwide.

METHODS: Individual participant data were uniformly processed using HALFpipe to construct voxelwise statistical images of executive processing and task load contrasts. Parameter estimates extracted from regions of interest were entered into multilevel Bayesian models to examine regional and whole-brain effects of diagnosis and, within OCD, the influence of medication status, symptom severity, and age of onset on task activation.

RESULTS: We observed a robust task activation pattern across individuals with OCD and control participants in executive processing regions across tasks. Relative to control participants, individuals with OCD showed moderate to very strong evidence of weaker activation of the dorsolateral prefrontal cortex, precuneus, frontal eye fields, and inferior parietal lobule during executive function (all positive posterior probabilities <0.1). Individuals with OCD also showed stronger activation in regions of the default mode network during executive function relative to control participants. We found little evidence for differential activation during executive function in task-positive regions related to disease onset, severity, and medication status.

CONCLUSIONS: In the first mega-analysis of fMRI studies of executive function in OCD, we found strong evidence of weaker frontoparietal activation during executive function tasks. Our findings also suggest a failure of default mode network regions to appropriately disengage during task performance in OCD.

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Obsessive-compulsive disorder (OCD) involves persistent distressing thoughts (obsessions) and repetitive behaviors or mental acts (compulsions) performed to reduce distress or prevent feared outcomes. These behaviors are thought to arise partially from impairments in executive function, a combination of subconstructs of the cognitive systems domain of the Research Domain Criteria (RDoC) (1). Executive function enables goal-directed behavior and depends on higher-order cognitive functions such as working memory (to hold and manipulate information) and planning (to think and act on that information). Executive dysfunction has been suggested as a possible endophenotype of OCD, representing a heritable mediator trait between genotype and phenotype that acts as a risk factor for the disorder (2,3).

Tower of London (TOL) and n-back tasks are often used during magnetic resonance imaging (MRI) to study the neural

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correlates of executive function. These tasks primarily engage the dorsal cognitive circuit, including the dorsolateral prefrontal cortex (dlPFC), presupplementary motor area (pre-SMA), and dorsal caudate (4). During these tasks, top-down regulatory control of behavior is provided by the frontoparietal network, encompassing the dlPFC, posterior parietal cortex, anterior cingulate, and insula, through connections with other networks including the dorsal cognitive circuit (5). Individuals with OCD typically perform worse on these tasks, with small-to-medium effect sizes for behavioral performance (5–7), while neuroimaging findings have been less consistent. Meta-analyses have found less task-related activation in individuals with OCD than in control participants in the frontal and cingulate gyrus, caudate (8–10), precuneus (8), postcentral and inferior occipital gyrus (9), and putamen (10) during executive function. However, stronger activation has also been reported in OCD during executive tasks in the posterior insula/putamen, precentral gyrus, dlPFC, and cuneus (9). As these meta-analyses combined executive and inhibitory control paradigms (where an automatic or prepotent motor response must be withheld), the cognitive construct most linked to OCD-related alterations remains unclear. Because executive function and inhibitory control rely on partially distinct frontostriatal networks (4), and executive function encompasses a broader spectrum of goal-directed cognitive processes, combining these paradigms might have obscured their specific neural underpinnings. Therefore, isolating executive function tasks is crucial to advancing our understanding of impaired goal directedness in OCD independent of inhibitory control deficits.

The ENIGMA (Enhancing Neuro Imaging and Genetics through Meta Analysis) consortium's OCD Working Group pools participant-level neuroimaging data into large clinically and ethnically diverse datasets that allow well-powered studies (11). We recently demonstrated for the first time in psychiatry a proof-of-concept that individual-participant functional MRI (fMRI) data from different task paradigms within another RDoC domain, i.e., negative valence, can be combined into a single large group-level analysis to compare domain-relevant activation between cases and controls and to investigate clinical subgroups of OCD (12). This participant-level approach to mega-analysis using whole-brain statistical maps provides a richer and more accurate characterization of activation than traditional coordinate-based meta-analyses (13,14). Given the available task data, the ENIGMA-OCD consortium is uniquely positioned to investigate the neural correlates of executive function separately from inhibitory control.

Here, we isolated several executive function paradigms, including visuospatial planning, working memory, and task switching, to study brain circuit function during executive processing in OCD independent of inhibitory control. We use executive function as an umbrella term that encompasses these partially distinct but related cognitive abilities within the RDoC cognitive systems domain. We pooled individual participant data from 15 different global samples that acquired fMRI data during executive function tasks in individuals with OCD and healthy control (HC) participants (both adults and children) into one image-based mega-analysis. We further investigated associations with relevant clinical characteristics of OCD, such as symptom severity, age of OCD onset, and medication status. Serotonin reuptake inhibitors were previously shown to normalize dorsal attention and default mode network (DMN) activation during a TOL task in adults with OCD (15). Earlier onset of OCD and greater symptom severity were correlated with worse performance on a visuospatial memory task (16) and Tower of Hanoi task (17), respectively. We hypothesized that relative to HC participants, individuals with OCD would show weaker activation during executive tasks in brain regions related to executive function and that this difference would increase with increasing task load. We expected that weaker executive processing–related activation would be associated with unmedicated status, early onset of OCD, and greater symptom severity.

METHODS AND MATERIALS

Study Population

We included 15 samples (7 unpublished) from the ENIGMA-OCD consortium, an international collaboration between sites with legacy historical neuroimaging data from individuals with OCD as well as HC participants. The samples spanned 10 countries across 4 continents. While some sites contributed more than one sample, there was no overlap in participants across samples. Trained personnel administered diagnostic tools based on DSM criteria to diagnose OCD, while OCD severity was measured using the (Children's) Yale-Brown Obsessive Compulsive Scale ([C]Y-BOCS) (18,19). HC participants had no psychiatric diagnosis or psychotropic medication use. Each sample applied its own inclusion and exclusion criteria based on the original study's research questions and task performance cutoffs; we maintained these criteria in the current analysis (see Supplemental Methods for additional inclusion and exclusion information). At each participating site, participants provided informed consent, and local review boards approved the use of deidentified data by the ENIGMA-OCD consortium.

Executive Function Tasks

Participants in each sample completed one of the following executive function tasks in the MRI scanner: TOL (7 samples), n-back (5 samples), and task-switching (3 samples) tasks (Table 1). Each task included trials testing executive function, enabling us to create one common contrast across paradigms: cognitive load versus no load. We previously used a similar approach for negative valence paradigms (12). Many of these tasks (9 samples) also included different difficulty levels, enabling us to also create a contrast that models increased cognitive effort with increasing task load.

Due to task design variability, performance metrics were not directly comparable across tasks. Therefore, we restricted our analysis of task performance to the TOL tasks, where sufficient consistency allowed for meaningful comparisons (see Supplemental Methods).

MR Image Acquisition and Processing

MRI data acquisition was not prospectively harmonized; sites contributed preexisting data (Table S1). Instead, we harmonized image processing across samples using the

Table 1. Task Characteristics of Studies Included in the Mega-Analysis

Site Principal Investigator	City, Country, Sample	Task	Executive Processing Events	Control Events	OCD, *n*	HC, *n*
Van den Heuvel	Amsterdam, NDL, 1	TOL	1–5 step TOL	Counting	20	20
Van den Heuvel	Amsterdam, NDL, 2	n-back	1–3 back	0-back	39	33
Van den Heuvel	Amsterdam, NDL, 3	TOL	1–5 step TOL	Counting	65	25
Huyser	Amsterdam, NDL, 4	TOL	1–5 step TOL	Counting	27	23
Reddy	Bangalore, IND	n-back	2-back	0-back	38	27
Menchón/Soriano-Mas	Barcelona, ESP, 1	Task switching	Task switch	Task repeat	18	18
Menchón/Soriano-Mas	Barcelona, ESP, 2	Task switching	Task switch	Task repeat	21	0
Lazaro	Barcelona, ESP, 3	Task switching	Task switch	Task repeat	60	35
Thorsen	Bergen, NOR	TOL	1–5 step TOL	Counting	38	28
Beucke/Kathmann	Berlin, GER	n-back	1–3 back	0-back	49	45
Stein/Lochner	Cape Town, ZAF	n-back	1-back	0-back	14	9
Benedetti	Milano, ITA	TOL	1–5 step TOL	Counting	21	15
Kwon	Seoul, KOR	TOL	1–4 step TOL	Counting	17	21
Voon	Shanghai, CHN	n-back	1–2 back	0-back	24	27
Stewart	Vancouver, CAN	TOL	1–5 step TOL	Counting	34	19

CAN, Canada; CHN, China; ESP, Spain; GER, Germany; HC, healthy control; IND, India; ITA, Italy; KOR, Korea; NDL, the Netherlands; NOR, Norway; OCD, obsessive-compulsive disorder; TOL, Tower of London; ZAF, South Africa.

open-source containerized HALFpipe version 1.2.2 (20) (see Supplemental Methods) to preprocess the structural and functional images and extract the task contrasts of interest. HALFpipe was specifically designed to accommodate multisite fMRI data with heterogeneous acquisition parameters, including differences in field strength and voxel size. Using default settings within HALFpipe, structural preprocessing included skull stripping, tissue segmentation, and spatial normalization, while functional preprocessing included motion correction and calculation of 6 rigid-body motion parameters, slice time correction (if slice acquisition order was known), susceptibility distortion correction (if field maps were available), coregistration, spatial normalization, smoothing with a 6-mm full width at half maximum Gaussian kernel, and extraction of noise components with independent component analysis–based automatic removal of motion artifacts (ICA-AROMA) (21).

We excluded participants with mean framewise displacement >1.0 mm. Processed data were also subjected to a quality assessment at each site according to harmonized guidelines (see Supplemental Methods).

First-Level Contrast Parameter Estimate Maps

The first-level contrast of interest across tasks compared conditions that test executive functions (planning trials in the TOL task, working memory trials in the n-back task, and switch trials in the task-switching task) with baseline conditions (counting trials in the TOL task, 0-back trials in the n-back task, and nonswitch trials in the task-switching task) (Table S2). The task load contrast modeled increasing cognitive effort, capturing stepwise variations in cognitive demand across conditions.

Analyses

The analysis plan and hypotheses were preregistered at http://osf.io/ebtpk, and analysis scripts are available at http://github.com/nadza-dz/task-based-fMRI-processing-pipeline-ENIGMA-OCD.git. We used the same processing and analysis pipeline as in Dzinalija *et al.* (12) for negative valence processing.

Region-of-Interest Analyses. We investigated the regions of interest (ROIs) identified in Nitschke *et al.*'s (22) meta-analysis of the TOL task in HC participants (including both adult and pediatric samples): dlPFC, frontal eye fields (FEFs), pre-SMA, inferior parietal lobule (IPL), precuneus, caudate, anterior insula, rostrolateral PFC, posterior cingulate, inferior occipital gyrus (IOG), and inferior temporal gyrus (ITG) (Table S3). These ROIs were selected based on their involvement in the TOL task; however, they are also relevant to other executive function tasks, as they form part of common neural networks underlying cognitive control, planning, and problem solving (23). The coordinates of peak activation in cortical regions identified by Nitschke *et al.* (22) were warped to MNI152 NLIN 2009c (asymmetric) space, and a sphere of 5 mm was created around each coordinate. The Melbourne subcortical atlas scale 1 (24) was used to identify the caudate. The mean activation of all voxels within an ROI was extracted from the *z*-statistic maps of each participant's first-level executive and task load contrasts, provided that there was signal in >30% of voxels in the ROI [as done in (12)]. For ROIs for which two Montreal Neurological Institute (MNI) coordinates exist per hemisphere, we created spheres at each coordinate and averaged activation across all voxels within the 2 spheres.

Rather than applying separate linear models to each ROI, all regions were entered simultaneously into one Bayesian multilevel model [RBA version 1.0.10 (25)] that considers the shared nonindependent information across brain regions (derived from 1 participant) in one statistical model. Using a noninformative Gaussian prior, the model was estimated with 4 Markov chains of 4000 iterations each, and convergence was confirmed by Rhat <1.1. A detailed discussion of the advantages of this approach is provided in Dzinalija *et al.* (12) and Chen *et al.* (25), but briefly, this approach captures the complex dependencies in the data, dissolves the multiple

testing problem, and unlike null hypothesis significance testing, allows us to test the credibility of our hypotheses directly. We infer the credibility of evidence of an effect from the area under the positive posterior distribution (see Supplemental Methods), summarized as the positive posterior probability (P+), with values <0.10 or >0.90 indicating moderate evidence, <0.05 or >0.95 indicating strong evidence and <0.025 or >0.975 indicating very strong evidence of an effect (25).

We investigated the main effect of executive function across all tasks and participants (participants with OCD and HC participants). Our main effect of interest was the case-control effect, with further analyses for clinical subgroups of OCD. To investigate the effect of age at OCD onset, we performed pairwise comparisons of individuals with early-onset OCD (age of onset <18), individuals with late-onset OCD (age of onset ≥18), and HC participants, in adults only. For all other analyses, we grouped adults (age ≥18) and children (age <18). We investigated the effect of current medication status by pairwise comparisons of medicated individuals (taking any psychotropic medication), unmedicated individuals, and HC participants. We assessed the effect of symptom severity using (C)Y-BOCS score as a continuous variable. Sample, age, and sex were entered as covariates of no interest in each analysis.

Sensitivity Analyses. This study is not intended as a methods comparison; therefore, we performed select sensitivity analyses specifically to assess the robustness of our findings, consistent with the primary aim of investigating executive function in OCD. For each ROI analysis on the executive contrast, we performed a leave-one-sample-out analysis to test the robustness of our results to sample effects. To facilitate comparison with more conventional fMRI analyses, we also compared Bayesian multilevel results for the executive contrast with a classical frequentist inference approach using a directly comparable multilevel mixed-effects linear model, including random effects for sample and participant, thereby modeling ROIs nested within participants and participants nested within samples. To assess the influence of sample correction method, we compared Bayesian results that incorporate sample as a covariate of no interest with those obtained using ComBat harmonization for the executive contrast of case-control effects. Finally, we considered potential task effects in two ways. First, we selectively examined the contrasts of interest within the TOL tasks to determine whether the observed activation patterns were consistent with previous literature, as the TOL is both the most commonly used paradigm to assess executive function and the most represented task in our dataset. Second, we explored including task as a covariate of no interest to account for potential task-related variance across contrasts. Including both task and sample as covariates was not feasible due to near-perfect collinearity between sample and task, which prevented model convergence. Therefore, we included only task as a covariate in this sensitivity analysis.

Whole-Brain Analyses. To apply the Bayesian multilevel model to the entire brain, whole-brain analyses were performed in functionally defined anatomical parcellations based on the Schaefer-Yeo 7-network 200-parcel atlas (26) and the Melbourne subcortical atlas scale 2 (24). *z*-Statistic maps of each participant's first-level contrasts were parcellated, and activation was entered into identical Bayesian multilevel group analyses as explained above. To determine the main effect of executive function across all tasks, we used an intercept model pooling all participants (HC participants and individuals with OCD) during executive function. Covariates of no interest were sample, sex, and age.

RESULTS

Participants

The final sample included 475 participants with OCD (51.2% female, mean ± SD age = 29.4 ± 12.4) and 345 HC participants (52.8% female, mean ± SD age = 28.7 ± 11.9) (Table 2; Table S4). See Supplemental Methods for exclusions (n = 16 OCD, n = 25 HC) and sample sizes per analysis.

Task Performance

Accuracy was comparable between groups in TOL tasks, except in one sample where individuals with OCD had lower performance than HC participants (Table S5).

Task Effects: Executive Function and Task Load

We compared activation during executive function relative to the baseline condition across all participants (cases and controls), for all tasks combined and specifically for TOL tasks (Figure 1A). Across all tasks, there was very strong evidence of stronger activation in all predefined ROIs during executive function (all P+ ≥ 0.99) except the right IOG (P+ = 0.53) and left cingulate gyrus (P+ < 0.001). Within TOL tasks, there was

Table 2. Demographic Characteristics of the Total Sample

	OCD, n = 475	HC, n = 345	Statistic
Sex			
Female	243 (51.16%)	182 (52.75%)	$\chi^2_1 = 0.14$, $p = .7$
Male	232 (48.84%)	163 (47.25%)	
Age, Years	29.4 (12.42)	28.7 (11.91)	$t_{818} = -0.81$, $p = .42$
<18	101 (21.26%)	67 (19.42%)	
≥18	374 (78.74%)	278 (80.58%)	
Age of OCD Onset			
Onset <18	311 (65.47%)	–	–
Onset ≥18	143 (30.11%)	–	
Missing data	17 (3.58%)	–	
Medication			
Medicated	234 (49.26%)	–	–
Unmedicated	240 (50.53%)	–	
Missing data	1 (0.21%)	–	
(C)Y-BOCS	23.73 (7.29)	–	
Missing data	6 (1.26%)	–	

Data are expressed as mean (SD) or n (%). Medication status was measured at the time of scan.

(C)Y-BOCS, (Children's) Yale-Brown Obsessive Compulsive Scale; HC, healthy control; OCD, obsessive-compulsive disorder.

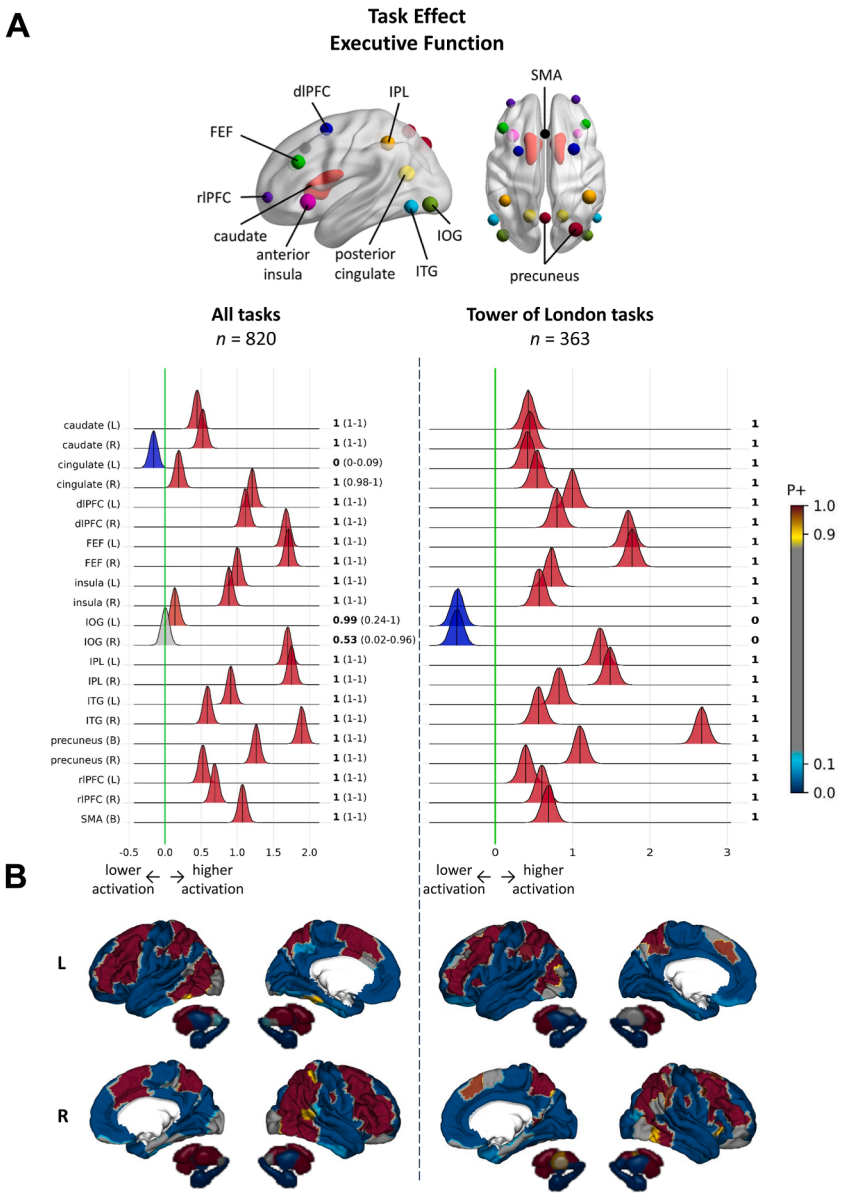


Figure 1. Main effect of executive function across all participants. **(A)** Region-of-interest results from Bayesian multilevel analyses of group-level executive contrast across individuals with obsessive-compulsive disorder (OCD) and healthy control (HC) participants in all tasks (*N* tasks = 15, *n* participants = 820) and in only Tower of London tasks (*N* tasks = 7, *n* participants = 363). Posterior probability distributions express the credibility of an effect in each region. Next to each distribution, the posterior probability of a positive effect (P+) is shown in bold, as well as the range of values this probability took on in leave-one-sample-out sensitivity analyses (where this analysis was carried out). In regions with posterior distributions to the right of the green no-effect line, there is evidence of stronger activation during executive function, while in regions with posterior distributions to the left of this line, there is evidence of weaker activation during executive function. Regions are color coded to reflect the strength of evidence for an effect, where in (darker) red regions, there is stronger evidence of activation during executive function (P+ values >0.90 indicate moderate to very strong evidence for a positive effect). In (darker) blue regions there is stronger evidence of deactivation during executive function (P+ values <0.10 indicate moderate to very strong evidence for a negative effect). In gray regions, there is no strong evidence of activation or deactivation during executive function. Values on the x-axis represent the difference in regional activation levels between executive and control trials (expressed as difference in *z* scores). **(B)** Whole-brain effects (P+ values) from Bayesian multilevel analyses. P+ values derived from Bayesian multilevel analyses denote the probability that there is stronger brain activation in a given region of the Schaefer 200-parcel 7-network cortical atlas and Melbourne 32-region subcortical atlas. Lateral and medial views of the cortex are displayed. B, bilateral; dlPFC, dorsolateral prefrontal cortex; FEF, frontal eye field; IOG, inferior anterior occipital gyrus; IPL, inferior parietal lobule; ITG, inferior temporal gyrus; L, left; R, right; rlPFC, rostrolateral prefrontal cortex; SMA, supplementary motor area.

very strong evidence of weaker activation in the bilateral IOG (P+ < 0.001) and stronger activation in all other ROIs (P+ > 0.99). There was stronger task load–related activation in all ROIs (Figure S1A), in TOL tasks and all tasks together (P+ > 0.99).

Whole-brain results confirmed task-positive activation in frontoparietal and dorsal attention regions and showed weaker activation in prefrontal and temporal regions of the DMN for both contrasts (Figure 1B; Figure S1B).

Brain Activity During Executive Function in Participants With OCD Versus HC Participants

In ROI analyses, individuals with OCD, relative to HC participants, showed moderate evidence of weaker activation in the bilateral dlPFC, left FEF, left ITL, right precuneus, and bilateral (pre-)SMA (0.05 < P+ ≤ 0.1) and strong-to-very-strong evidence of weaker activation in the right FEF, bilateral IPL, and bilateral precuneus (0.01 < P+ < 0.03) during executive function in all tasks (Figure 2A). Results were very similar when considering only TOL tasks. In the task load contrast, there was moderate evidence for weaker activation in individuals with OCD relative to HC participants in the bilateral caudate, right dlPFC, bilateral FEFs, left IPL, bilateral precuneus, and SMA (0.06 < P+ < 0.09) when investigating all tasks but not when looking at TOL tasks alone (Figure S2A).

In whole-brain analyses, both the executive and task load contrasts showed evidence for weaker activation in dorsal attention and frontoparietal regions in OCD. The executive

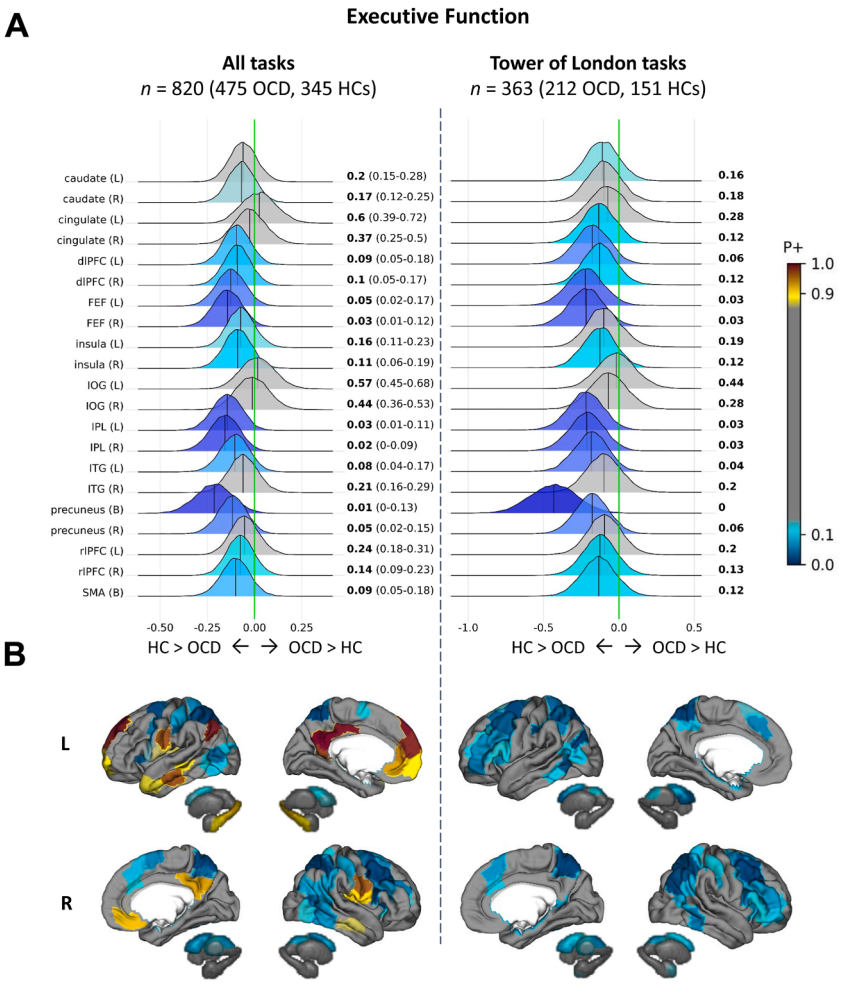


Figure 2. Case-control differences in executive function. **(A)** Region-of-interest results from Bayesian multilevel analyses. Distributions to the right of the green no-effect line represent regions in which individuals with obsessive-compulsive disorder (OCD) show evidence for stronger activation than healthy control (HC) participants. The (darker) red color represents regions in which individuals with OCD show moderate to very strong evidence for stronger activation than HC participants. Regions with posterior distributions to the left of the no-effect line show evidence for stronger activity in HC participants than in participants with OCD. The (darker) blue color represents regions in which HC participants show moderate to very strong evidence for stronger activation than individuals with OCD. In gray-colored regions, there is no evidence of a difference between HC participants and individuals with OCD. Values on the x-axis represent the difference in regional activation levels between HC participants and participants with OCD (expressed as difference in *z* scores). **(B)** Whole-brain effects from Bayesian multilevel analyses. P+ indicates posterior probability of a positive effect. B, bilateral; dlPFC, dorsolateral prefrontal cortex; FEF, frontal eye field; IOG, inferior anterior occipital gyrus; IPL, inferior parietal lobule; ITG, inferior temporal gyrus; L, left; R, right; rlPFC, rostrolateral prefrontal cortex; SMA, supplementary motor area.

contrast also showed evidence of stronger activation in default mode regions (i.e., medial prefrontal and posterior cingulate) (see Figure 2B; Figure S2B).

Executive Function in Clinical Subgroups of OCD: Age of Onset, Medication Status, and Symptom Severity Effects

Age of OCD Onset. There was moderate evidence of weaker activation during executive function in adults with early-onset OCD than in adults with late-onset OCD in the bilateral precuneus (P+ = 0.90) (Figure 3A) but not in any other predefined ROIs. Whole-brain analyses demonstrated widespread weaker activation in early-onset OCD across prefrontal, parietal, and temporal regions relative to late-onset OCD. These effects were absent for task load–related activation.

Medication Status. There was no evidence for different activation in any predefined ROIs during executive function between medicated and unmedicated individuals with OCD (Figure 3). Whole-brain analyses showed moderate evidence for weaker activation in orbitofrontal, posterior cingulate, and temporal pole regions during executive function in unmedicated than medicated individuals. None of these results were found for task load–related activation, either in ROI or whole-brain analyses.

Symptom Severity. There was no evidence of an association between symptom severity and brain activation during executive function, either in ROI or whole-brain analyses (Figure 3). However, there was moderate to very strong evidence that greater symptom severity correlated with stronger task load–related activation in all investigated ROIs (all P+ > 0.90), except the left insula (Figure S3A). Whole-brain analyses indicated that OCD severity was associated with stronger activation in dorsal prefrontal and inferior parietal regions (Figure S3B).

Sensitivity Analyses

Leave-one-sample-out validation showed low variability in case-control analyses and clinical subgroup analyses, indicating high robustness of results to sample-specific effects (Figure S5). Results were extremely similar in frequentist statistical models (Table S6) and Bayesian models. Sample correction using ComBat yielded results nearly identical to those obtained by modeling sample as a covariate (Figure S6). Similarly, including task as a covariate instead of sample

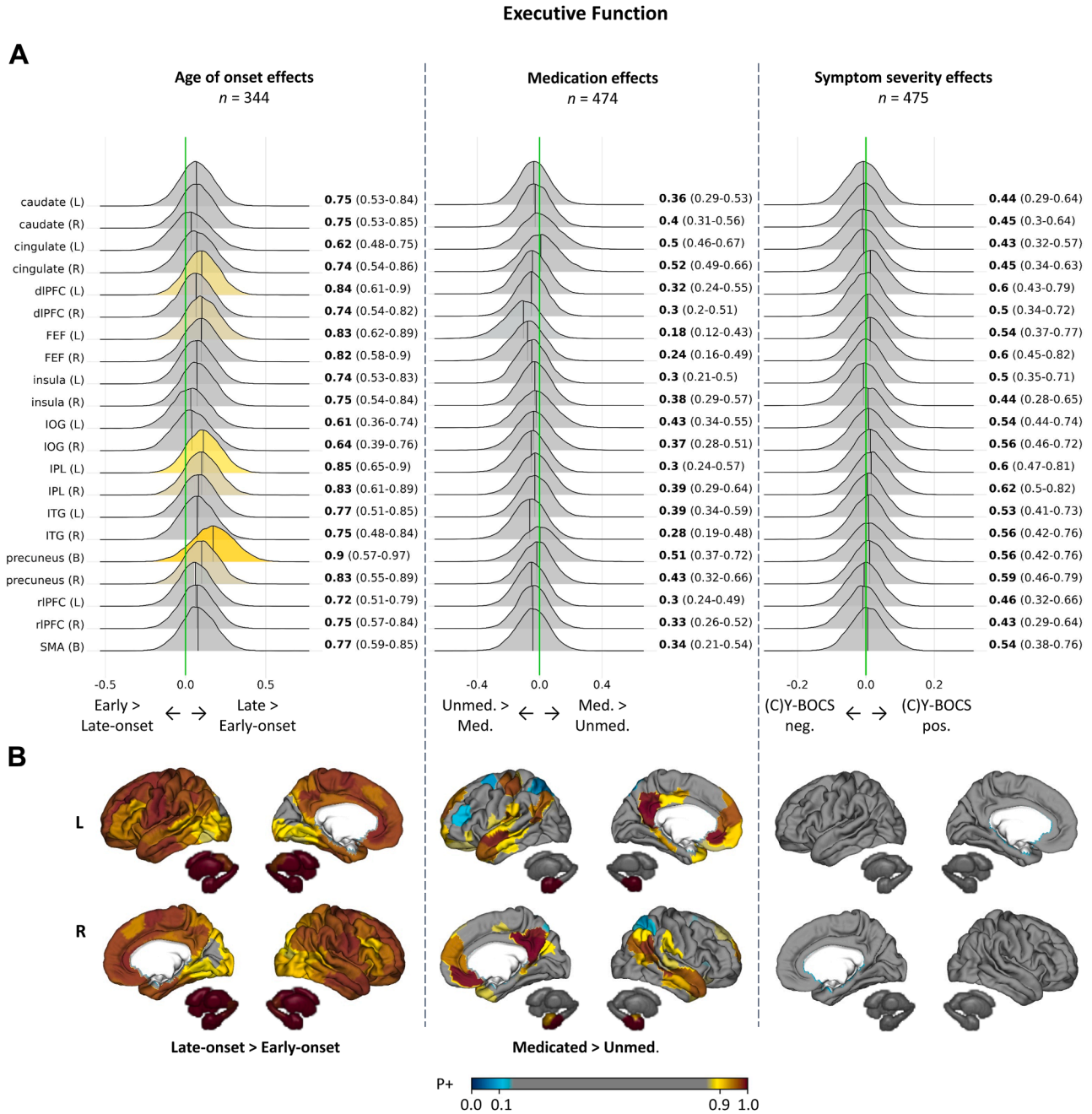


Figure 3. Effects of clinical features of obsessive-compulsive disorder on executive function. **(A)** Region-of-interest effects of age of onset, medication status, and symptom severity during executive function. **(B)** Whole-brain analyses of executive function. B, bilateral; (C)Y-BOCS, (Children's) Yale-Brown Obsessive Compulsive Scale; dlPFC, dorsolateral prefrontal cortex; FEF, frontal eye field; IOG, inferior anterior occipital gyrus; IPL, inferior parietal lobule; ITG, inferior temporal gyrus; L, left; neg., negative; P+, positive posterior probability; pos., positive; R, right; rlPFC, rostrolateral prefrontal cortex; SMA, supplementary motor area; Unmed., unmedicated.

yielded results nearly identical to the original model, indicating that case-control effects were robust to potential task-related variance (Figure S6).

DISCUSSION

Using a mega-analytic approach, we examined neural differences in the RDoC cognitive systems domain between OCD and HC participants across 15 global samples using participants' whole-brain executive and task load–related activation maps. In almost all ROIs relevant for executive processing, we found strong task activation, indicating that we successfully captured domain-specific activation during executive function. Consistent with our hypotheses, we found weaker activation in OCD in the PFC, ITG, precuneus, IPL, FEF, and

(pre-)SMA. With increasing task load, individuals with OCD showed weaker activation than HC participants in these regions and in the caudate and dlPFC. Contrary to expectations and our previous findings on negative valence processing (12), clinical heterogeneity in OCD had little impact on activation strength during executive tasks, although we found some evidence that early-onset OCD may be associated with weaker executive processing–related activation, while greater symptom severity appears to be linked to stronger task load activation.

Weaker activation in task-relevant brain regions in individuals with OCD relative to HC participants was reported in multiple meta-analyses (8–10), specifically in the frontal gyri and precuneus, closely matching our results. These regions are considered part of the frontoparietal and dorsal cognitive networks (4) and are involved in goal-directed behavior, possibly relying on the precuneus, IPL, and FEFs to guide attention processes (27–29) and on the dlPFC and ITG to integrate multimodal sensory information to guide decision making (30,31). This supports the hypothesis that decreased activation during executive processing in OCD mediates the inability of individuals with OCD to override compulsions and act in a goal-directed way.

Although clinical features (medication status, age of onset, and symptom severity) showed no strong associations with executive processing–related activation in predefined ROIs, whole-brain analyses revealed weaker activation in frontoparietal and temporal regions in early-onset OCD compared with late-onset OCD. This is consistent with our hypothesis and earlier findings (16) that early-onset OCD is associated with weaker executive function activation, although it partially conflicts with meta-analytic findings that individuals with early-onset OCD perform worse on visual memory tasks but not on verbal memory or executive control tasks outside the scanner (32). Due to task design heterogeneity, we could not investigate performance differences between OCD and HC participants across all tasks or relate observed brain activation differences to performance. In TOL tasks, only one sample showed accuracy differences between participants with OCD and HC participants, suggesting that activation differences are unlikely to be driven by accuracy, although we cannot rule out differences in other performance metrics such as response times.

We found no association between symptom severity and executive processing activation, although severity did positively correlate with task-load activation. Paradoxically, individuals with more severe OCD showed stronger task load–related activation in dorsal prefrontal and inferior parietal regions, whereas on average, individuals with OCD demonstrated weaker activation during executive function relative to HC participants. To explore whether any clinical factors might account for this unexpected pattern, we conducted post hoc analyses within the subset of participants that was used to study task-load activation. These analyses revealed that greater symptom severity was associated with older age at OCD onset in this subsample (Figure S7). This exploratory observation in a limited subsample does not allow us to conclude whether later-onset status explains the paradoxical activation pattern, although it raises the possibility that later-onset OCD may rely on compensatory recruitment of task-relevant regions under higher cognitive load. Interestingly, previous studies did not find an association between OCD severity and brain activation during executive tasks (33), except in the most severe cases (Y-BOCS $>$ 32) (34), further underscoring the idea that phenotypic heterogeneity in OCD also extends to neural activation.

Alongside weaker executive processing–related activation, individuals with OCD showed less deactivation in DMN regions, suggesting difficulty in suppressing the DMN and engaging task-relevant networks. While it remains unclear whether switching between executive and default processing modes is impaired in OCD, limited research suggests altered DMN activity and connectivity, both at rest and during task performance (35–37). Specifically, prior ENIGMA-OCD analyses revealed weaker resting-state functional connectivity within regions of the DMN—specifically between the precuneus/posterior cingulate cortex and dorsomedial PFC—and between the DMN and other task-relevant networks such as the frontoparietal and dorsal attention networks (35). Task-based findings are consistent with this pattern, showing reduced DMN connectivity during a reward task (between the posterior cingulate cortex and the ventromedial PFC) (36) and less deactivation in frontal DMN regions during an emotional processing task when shifting from rest to viewing pleasant stimuli (37). This suggests that altered within- and between-network connectivity of the DMN may underlie difficulties in suppressing DMN activity to support goal-directed processing, possibly by impairing attentional control (38). A deficit in deactivating the DMN during task execution may not be specific to OCD, as a suppression deficit was also found during a working memory task in participants with remitted major depressive disorder and was related to rumination (39). This supports the theory that self-referential processing and internal regulation states that are governed by the DMN (40) may be disrupted in OCD in a way that impairs the ability to override internally generated obsessions and resulting compulsions to act in a goal-directed way. Further research is needed to clarify whether there is an impairment in OCD in the ability to disengage the DMN when transitioning from rest to task and whether this may present a transdiagnostic trait across psychiatric disorders.

The absence of expected associations between certain clinical features of OCD and task-related activation may stem from the limited phenotypic detail of the included samples, such as past medication use, comorbidities, and symptom subtypes. This constraint prevented more sensitive subgroup analyses that might have identified important moderators of task effects. Like all retrospective analyses of legacy data, our study was limited by the lack of harmonized data collection and reporting. Nonetheless, our results proved robust to sample effects, as leave-one-sample-out analyses did not suggest undue influence of larger samples, unlike what was previously observed in our negative valence domain analyses (12). While sensitivity analyses using frequentist models yielded less pronounced effects, Bayesian multilevel models provided more robust and reliable evidence for differences in activation by leveraging partial pooling across brain regions and eliminating the need for multiple testing corrections. Although different task paradigms captured various aspects of executive function, we demonstrated a strong executive processing effect in nearly all predefined ROIs across tasks. Moreover, results were very robust to task effects, as results of the analyses on the TOL tasks alone closely matched those from the combined-task analyses, particularly at the whole-brain level. This

suggests that the TOL task effectively captures the broader construct of executive function, which we were able to examine independently of inhibitory control—a limitation of all previous meta-analyses (8–10)—that may explain discordant findings.

Conclusions

Our findings support the hypothesis that the RDoC's cognitive systems domain is relevant to OCD and that impaired goal-directed behavior in OCD may stem from weaker activation of dorsal cognitive and frontoparietal circuits. This weaker activation of key task-positive regions may be associated with decreased decoupling from the DMN during task performance, pointing to potential neurocircuit-level dysfunctions in OCD.

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Raw individual participant data from this study are not publicly available due to consortium data-use agreements. Processed and deidentified tabulated ROI-based and whole-brain parcellated brain activation data will be made available through the ENIGMA Toolbox (enigma-toolbox.readthedocs.io) in accordance with ENIGMA consortium policies. The code used for analyses is available at http://github.com/nadza-dz/task-based-fMRI-processing-pipeline-ENIGMA-OCD.git.

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